

What is claimed is:

1. A pipelined fast Fourier transform (FFT) processor for receiving an input sequence, the processor comprising:
  - 5 at least one FFT triplet having first, second and third butterfly modules connected in series by selectable multipliers for selectively performing trivial co-efficient multiplication and complex co-efficient multiplication on output sequences of adjacent butterfly modules, each of the at least one FFT triplets terminating in a twiddle factor multiplier for applying a twiddle factor to an output of the third butterfly module of the respective triplet, the at least one FFT
  - 10 triplet for receiving the input sequence and for outputting a final output sequence representing an FFT of the input sequence.
2. The processor of claim 1, wherein each butterfly module includes a radix-2 butterfly unit and a feedback memory.
3. The processor of claim 2, wherein, for an input sequence of  $N$  samples, an output sequence  $X(k, n)$  of each butterfly module is equal to  $x(n) + (-1)^k x(n + \frac{N}{2})$ .
  - 15 4. The processor of claim 1, wherein at least one of the selectable multipliers for performing trivial co-efficient multiplication is integrated in an adjacent butterfly module.
  5. The processor of claim 1, wherein the selectable multipliers each include a multiplier and a switch for bypassing the multiplier.
- 20 6. The processor of claim 1, wherein the first and second butterfly modules are connected by a selectable multiplier for selectively applying trivial co-efficient multiplication.
7. The processor of claim 6, wherein the second and third butterfly modules are connected by a selectable multiplier for performing trivial co-efficient multiplication and a selectable multiplier for performing the complex co-efficient multiplication  $W_N^k$ .
- 25 8. The processor of claim 2, wherein, for an input sequence having  $N$  samples, the feedback memories for the first, second and third butterfly modules hold  $N/2$ ,  $N/4$  and  $N/8$  samples, respectively.
9. The processor of claim 1 wherein the input sequence is of length  $N$ , where

( $\log_2 N$ )mod3 = 1, the processor having a plurality of FFT triplets in seriatim and further including an FFT terminator having a butterfly unit and a corresponding memory sized to hold a single sample, the FFT terminator for receiving the output sequence from the final twiddle factor multiplier and for performing a butterfly operation on the received output sequence to 5 render an FFT of the input sequence.

10. The processor of claim 1 wherein the input sequence is of length  $N$ , where ( $\log_2 N$ )mod3 = 2, the processor having a plurality of FFT triplets in seriatim and further including an FFT terminator having first and second butterfly units having corresponding memories sized to hold two samples and a single sample respectively, the first butterfly unit 10 connected to the second butterfly unit by a selectable multiplier for selectively multiplying the output of the first butterfly unit by  $-j$  the FFT terminator for receiving the output sequence from the final twiddle factor multiplier and for performing a pair of butterfly operations on the received output sequence to render an FFT of the input sequence.

11. The processor of claim 1, wherein the twiddle factor multiplier is a cordic rotator.

15 12. A pipelined fast Fourier transform (FFT) processor for receiving an input sequence of  $N$  samples, the processor comprising:

at least one FFT triplet, the triplet having:

a first FFT stage having a first stage radix-2 butterfly unit for receiving the input sequence and for providing a first stage output sequence in accordance with a butterfly

20 operation performed on the input sequence, the first stage radix-2 butterfly unit having a first feedback memory connected thereto;

a second FFT stage having a selectable multiplier for selectively multiplying the first stage output sequence by a trivial co-efficient, and a second stage radix-2 butterfly unit for providing a second stage output sequence in accordance with the butterfly operation

25 performed on the output of the selectable multiplier, the second stage radix-2 butterfly unit having a second feedback memory connected thereto; and

a third FFT stage having a multiply selectable multiplier for selectively multiplying the second stage output sequence by at least one of the trivial co-efficient and a complex co-efficient, a third stage radix-2 butterfly unit for providing a butterfly output in accordance with 30 the butterfly operation performed on the output of the multiply selectable multiplier, the third stage radix-2 butterfly unit having a third feedback memory connected thereto, and a

multiplier for multiplying the butterfly output by a twiddle factor, to provide an output sequence corresponding to an FFT of the input sequence.

13. The FFT processor of claim 12, wherein each of the first, second and third stage output sequences  $X(k, n)$  is equal to  $x(n) + (-1)^k x(n + \frac{N}{2})$ .

5 14. The FFT processor of claim 12, wherein at least one of the butterfly units includes an integrated pre-multiplication function for applying a trivial co-efficient multiplication to a received input sequence.

The FFT processor of claim 12, further including an FFT terminator determined in accordance with the length  $N$  of the input sequence.

10 15. A pipelined fast Fourier transform (FFT) processor for receiving an input sequence of  $N$  samples, the processor comprising:

at least one FFT triplet, the triplet having:

a first FFT stage having a first stage radix-2 butterfly unit for receiving the input sequence and for providing a first stage output sequence in accordance with a butterfly

15 operation performed on the input sequence, the first stage radix-2 butterfly unit having a first feedback memory connected thereto;

a second FFT stage having a multiply selectable multiplier for selectively multiplying the first stage output sequence by at least one of the trivial co-efficient and a constant complex co-efficient, and a second stage radix-2 butterfly unit for providing a second stage output sequence in accordance with the butterfly operation performed on the output of the selectable multiplier, the second stage radix-2 butterfly unit having a second feedback memory connected thereto; and

20 a third FFT stage having a selectable multiplier for selectively multiplying the second stage output sequence by a trivial co-efficient, a third stage radix-2 butterfly unit for providing a butterfly output in accordance with the butterfly operation performed on the output of the selectable multiplier, the third stage radix-2 butterfly unit having a third feedback memory connected thereto, and a multiplier for multiplying the butterfly output by a twiddle factor, to provide an output sequence corresponding to an FFT of the input sequence.

25 16. The FFT processor of claim 15, wherein each of the first, second and third stage

output sequences  $X(k, n)$  is equal to  $x(n) + (-1)^k x(n + \frac{N}{2})$ .

17. The FFT processor of claim 15, wherein at least one of the butterfly units includes an integrated pre-multiplication function for applying a trivial co-efficient multiplication to a received input sequence.

5 18. The FFT processor of claim 15, further including an FFT terminator determined in accordance with the length  $N$  of the input sequence.

10 19. The FFT processor of claim 18, wherein the FFT terminator includes a butterfly module having a memory sized to store a single sample, for receiving as a terminator input, the output of the third FFT stage multiplier and for performing a butterfly operation on the terminator input to render an FFT of the input sequence of  $N$  samples.

20. The FFT processor of claim 18, wherein the FFT terminator includes a first butterfly module having a memory sized to store a pair of samples, for receiving as a terminator input, the output of the third stage multiplier and for performing a butterfly operation on the terminator input, and a second butterfly module connected to the first butterfly module of the 15 terminator by a selectable multiplier, the selectable multiplier for selectively multiplying the output of the first butterfly module of the terminator by  $-j$ , the second butterfly module having a memory sized to store a single sample and for performing a butterfly operation on the selectively multiplied output of the first butterfly module of the terminator to render an FFT of the output sequence.

20 21. A method of performing an FFT on a sequence of  $N$  samples in an FFT processor having a butterfly module, the method comprising:

for all integers  $1 \leq x \leq \log_2 N$ , repeating the steps of

receiving and buffering  $\frac{N}{2^x}$  samples at a time from a sequence having  $N$

samples;

25 generating a 2-point FFT using the  $n^{th}$  and the  $\left(n + \frac{N}{2^x}\right)^{th}$  samples;

selectively multiplying the generated 2-point FFT sequence by a complex valued multiplicand;

terminating the FFT using a termination sequence determined in accordance with a  $(\log_2 N) \bmod 3$  relationship.

22. The method of claim 21 wherein the complex valued multiplicand is selected from a list including  $1$ ,  $-j$ ,  $\frac{\sqrt{2}}{2} - j \frac{\sqrt{2}}{2}$ , and a complex twiddle factor co-efficient.

5 23. The method of claim 21 wherein  $(\log_2 N) \bmod 3 = 1$  and the step of terminating the FFT includes buffering a sample received from the final selective multiplication and performing a 2-point FFT using the buffered sample and the subsequent sample in the sequence to obtain the FFT of the sequence of  $N$  samples.

24. The method of claim 21 wherein  $(\log_2 N) \bmod 3 = 2$  and the step of terminating the  
10 FFT includes:

buffering a pair of samples received from the final selective multiplication and performing pair-wise 2-point FFTs using the two buffered samples and the two subsequent samples in the sequence;

selectively multiplying the result of the pair-wise 2 point FFT by  $-j$ ; and

15 buffering a sample received from the selective multiplication of the pair-wise 2-point FFT and performing a 2-point FFT using the buffered sample and the subsequent sample in the sequence to obtain the FFT of the sequence of  $N$  samples.